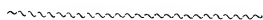


PROCEEDINGS

OF

THE ROYAL SOCIETY.



February 1, 1883.

THE PRESIDENT in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read :—

- I. “On the Electrical Resistance of Carbon Contacts.” By SHELFORD BIDWELL, M.A., LL.B. Communicated by Professor W. G. ADAMS, F.R.S. Received January 18, 1883.

1. Object of the Investigation.

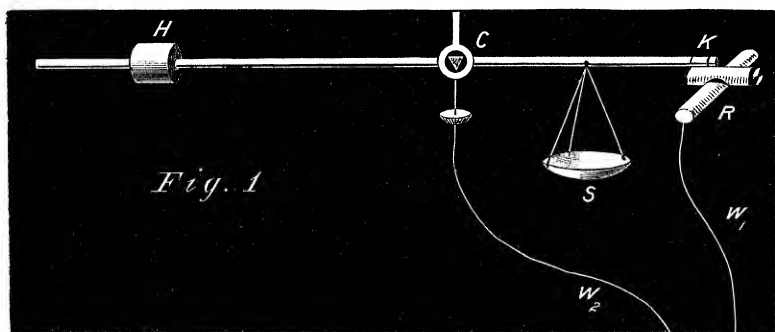
It is well known that the electrical resistance of carbon contacts diminishes with increased pressure, though, so far as I am aware, the phenomenon has never hitherto been systematically investigated. The experiments described in this paper were begun with the object of establishing a quantitative relation between pressure and resistance; but the subject grew considerably under treatment; fresh facts from time to time claimed attention, and several interesting details, not, I believe, previously observed, were eventually brought to light.

Loose contacts are proverbial for the uncertainty of their action, and it was to be expected that the investigation would prove troublesome and the results obtained by no means uniform. By multiplying experiments, however, the element of uncertainty was to a great extent removed, and in most cases it was found possible to indicate a general law with tolerable certainty.

2. Apparatus for Regulating Pressure.

The instrument used for regulating the pressure is shown in fig. 1.

The apparatus consists of a little balance. HK is a light steel rod formed of a fine knitting needle balanced at C on a knife-edge, which



is fixed at right angles to it. To one end, K, is attached a split tube of thin copper for holding short rods of the different materials to be tested, which are held so as to press at right angles upon another rod, R, supported in a spring clamp. Midway between C and K is hung the scale-pan S, and at H is a sliding counterpoise, which, at the beginning of an experiment, is so adjusted that a weight of .01 gm. in the scale-pan will just bring K and R into contact with each other. Electrical connexion is made through the wires W_1 and W_2 , the former of which is attached to the clamp holding R, and the latter communicates with a mercury cup, into which dips a wire attached to the rod HK at the point C. It is evident that the pressure between K and R will be equal to half the weight in the scale-pan S.

3. *Relation between the Pressure of Carbon Contacts and their Resistance.*

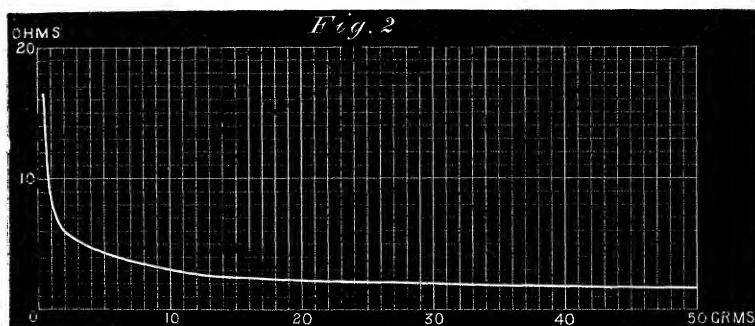
Two short rods of electric light carbon, 6 millims. in diameter, were placed in the instrument in the positions shown at K and R, and the resistance with different pressures measured in the ordinary manner with a Wheatstone's bridge. The means of three series of such measurements made under as nearly as possible the same conditions, are given in Table I.

Table I.—Relation between Pressure and Resistance when measured in the ordinary way.

Pressure.		Resistance.
Grammes.		Ohms.
.25	.....	16.10
.5	.....	11.00
1	.....	8.43
1.5	.....	6.70
2	.....	6.15

Pressure. Grammes.	Resistance. Ohms.
2.5	5.90
3	5.13
3.5	5.00
4	4.60
4.5	4.33
5	4.23
7.5	3.53
10	3.06
12.5	2.80
15	2.60
17.5	2.46
20	2.33
25	2.16
50	1.86

From the above results the curve fig. 2 has been constructed, where the abscissæ represent the pressures at the points of contact and the ordinates the resistance in ohms. The curve shows clearly that the greatest variations occur when the pressure is small and the resistance comparatively high.



4. *Change of Resistance partly due to Effect of Current.*

In making measurements of the kind above described, the details of the arrangements were from time to time varied. Different proportional coils were used and different numbers of battery cells; and it soon became evident that the resistance of the carbon contact was largely dependent on the strength of the current used to measure it. In Table II (giving the mean of two series of observations) is shown the result of using one, two, three, and four cells successively.

Table II.—Effect upon Resistance of Increased Electromotive Force.

Pressure. Grams.	Resistance in ohms with			
	1 cell.	2 cells.	cells.	4 cells.
·25	11·10	7·20	4·70	3·55
·5	5·95	4·70	4·10	3·50
1	4·40	3·65	3·25	3·10
1·5	3·60	3·20	2·95	2·80
2	3·55	3·15	2·80	2·50
2·5	3·35	2·95	2·65	2·40
3	2·90	2·55	2·35	2·30
3·5	2·45	2·30	2·05	1·95
4	2·25	2·10	2·00	1·90
4·5	2·10	1·95	1·85	1·75
5	1·95	1·85	1·75	1·70
7·5	1·55	1·55	1·50	1·45
10	1·50	1·45	1·40	1·35
25	1·15	1·05	1·05	1·05

It became interesting to ascertain what would be the effect of making still further variations in the strength of the measuring current. A box of resistance coils was therefore inserted between the battery (two Leclanché cells) and the bridge arrangement; and the weight in the scale-pan remaining the same, various resistances were successively unplugged in the box. Table III gives a few of the measurements with pressures of ·5, 2·5, 7·5, and 25 grms. This table shows that the resistance of the carbon contacts varies greatly with the strength of the current when the pressure is small, and but very slightly when the pressure is great.

Table III.

Added resistance in circuit. Ohms.	Resistance in ohms with pressure of			
	·5 gm.	2·5 grms.	7·5 grms.	25 grms.
0	5·6	2·7	1·7	1·02
5	—	2·8	1·8	1·03
10	6·9	2·9	1·8	1·03
50	7·7	3·1	1·9	1·03
100	8·6	3·1	1·9	1·03
500	9·3	3·1	1·9	1·03
1000	9·7	3·1	1·9	1·03

It is clear therefore that the diminution of resistance which occurs when the pressure between carbon contacts is increased is not, under ordinary circumstances, due solely to the direct effect of pressure. For the diminished resistance which results from the increased pressure causes an increase in the strength of the current, the effect of which is a still further fall in the resistance. Thus the total diminution of resistance is due partly to increase of pressure, and partly to increased strength of current.

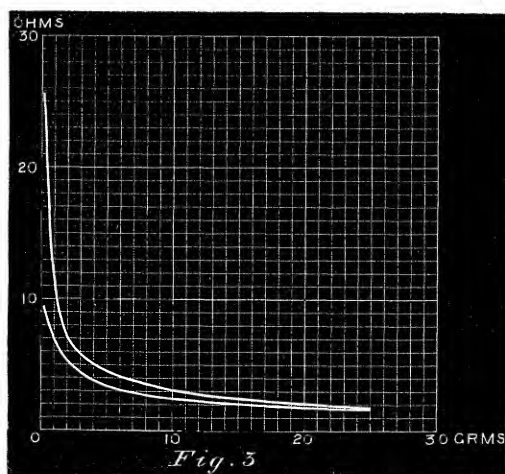
5. *Variation of Resistance with Varying Pressure and Constant Current.*

Table IV and the curves in fig. 3 show the results when special means were taken to maintain constant currents of $\cdot 1$ and $\cdot 001$ ampère respectively, the pressure at the contacts increasing from $\cdot 05$ to 25 grms.

Table IV.—Effect of Pressure upon Resistance of Carbon Contacts with Constant Currents.

Pressure. Grms.	Resistance in ohms with current of	
	$\cdot 1$ ampère.	$\cdot 001$ ampère.
$\cdot 05$	11 $\cdot 02$	68 $\cdot 00$
$\cdot 25$	9 $\cdot 27$	25 $\cdot 50$
$\cdot 5$	8 $\cdot 45$	17 $\cdot 75$
1	6 $\cdot 56$	11 $\cdot 75$
1 $\cdot 5$	5 $\cdot 53$	9 $\cdot 75$
2	5 $\cdot 34$	7 $\cdot 50$
2 $\cdot 5$	4 $\cdot 57$	6 $\cdot 50$
3	4 $\cdot 15$	5 $\cdot 85$
3 $\cdot 5$	4 $\cdot 03$	5 $\cdot 70$
4	3 $\cdot 63$	5 $\cdot 70$
4 $\cdot 5$	3 $\cdot 41$	4 $\cdot 95$
5	3 $\cdot 31$	4 $\cdot 95$
7 $\cdot 5$	2 $\cdot 95$	3 $\cdot 65$
10	2 $\cdot 51$	3 $\cdot 15$
15	2 $\cdot 10$	2 $\cdot 45$
20	1 $\cdot 89$	2 $\cdot 10$
25	1 $\cdot 67$	1 $\cdot 75$

It will be seen that with small pressures the resistance is largely dependent upon the strength of the current, but when the pressure is considerable, the resistance with weak and strong currents is nearly the same.



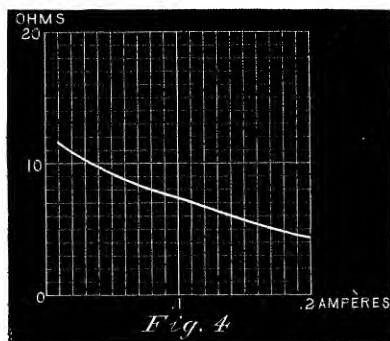
6. *Variation of Resistance with Varying Current and Constant Pressure.*

The same effect may be exhibited in another form by varying the current while the pressure remains constant. Table V gives the variations in the resistance with currents of from $\cdot 01$ to $\cdot 2$ ampère, the pressure at the point of contact being throughout 1 gram.

Table V.—Changes of Resistance produced by Current, the Pressure remaining Constant at 1 gram.

Current. Ampère.		Resistance. Ohms.
$\cdot 01$	.....	11 $\cdot 4$
$\cdot 02$	.....	10 $\cdot 8$
$\cdot 03$	.....	10 $\cdot 4$
$\cdot 04$	.....	9 $\cdot 8$
$\cdot 05$	.....	9 $\cdot 6$
$\cdot 06$	.....	8 $\cdot 9$
$\cdot 07$	.....	8 $\cdot 5$
$\cdot 08$	.....	8 $\cdot 2$
$\cdot 09$	.....	7 $\cdot 9$
$\cdot 1$	.....	7 $\cdot 6$
$\cdot 15$	.....	5 $\cdot 6$
$\cdot 2$	.....	4 $\cdot 5$

The results are also shown in the curve fig. 4.



7. *The Effect of Pressure on the Resistance of Carbon is Temporary.*

In order to ascertain whether the diminution of resistance under pressure was entirely of a temporary nature, or whether it continued in any degree after the pressure had been removed (the carbons of course being undisturbed) a special arrangement was made by means of which a 5 gm. weight could be placed in or taken out of the scale-pan without causing any appreciable oscillation. The weight was attached by a thread to one end of a horizontal lever, the lever being so supported that when the other end of it was depressed the weight was raised about a centimetre above the pan; this could be done without in any material degree disturbing the carbon contacts.

A weight of 1 gm. being in the scale-pan, the resistance of the contact was measured with the Wheatstone's bridge, and one Leclanché cell; the 5 gm. weight was then lowered into the pan, and a measurement made of the diminished resistance. The 5 gm. weight was again gently raised, and the resistance with a single gramme once more measured. In every case it was found to have returned almost exactly to its original value. Table VI gives six series of measurements thus made.

Table VI.—One Leclanché. Proportional Coils 10 and 1,000 ohms.

Pressure. Grms.	Resistance.					
	Ohms.	Oh ms.	Ohms.	Ohms.	Ohms.	Ohms.
·5	19	20	20	19·6	19·3	19·2
3	25	15	14	13·9	13·7	13·6
·5	20	20	20	19·9	19·5	20·0

The experiment was repeated with a resistance of 300 ohms between

the battery and the bridge, that the current might be smaller. The results are contained in Table VII, and are substantially the same as before.

Table VII.—Same arrangement as in Table VI, with a Resistance of 300 ohms between the Battery and Bridge.

Pressure. Grms.	Resistance.					
	Ohms.	Ohms.	Ohms.	Ohms.	Ohms.	Ohms.
·5	30·1	31·5	31·6	34·4	35·4	34·1
3	24·3	25·2	19·0	19·6	19·8	18·8
·5	32·9	33·2	34·4	36·4	35·1	36·4

It will be noticed, however, that the final resistance is almost invariably slightly higher than the original resistance; but this increased resistance gradually diminished, as may be seen by comparing the last figure of one column with the first of the next, and perhaps if time were given it would return to its original value. This is probably a thermo-electric effect.

8. *Effects of Heating Contacts.*

Since, as is well known, the resistance of a continuous conductor of carbon is diminished by heat, it would be reasonable to suppose that the diminution which the resistance of carbon contacts exhibits under the influence of increased currents is due merely to the heating effect of the current. Experiments made with the view of testing this hypothesis failed, however, to support it. Carbon contacts of various forms were heated in an air-bath, and their resistance measured at different degrees of temperature. The resistance was in every case found to vary irregularly (probably because, in consequence of the expansion due to heat, the relative positions of the points of contact were slightly altered) but, in general, rise of temperature was accompanied by a rise in the resistance. Thus, in one case with a pressure of 1 grm., the resistance which at 16° C. was 9 ohms, became at 50° 10·7 ohms. Upon another occasion the resistance increased from 11·9 ohms at 15° to 15·6 ohms at 36°. And again with a pressure of 5 grms., the resistance increased from 4·7 ohms at 17° to 5·7 ohms at 50°. In every case the resistance fluctuated considerably, rising and falling alternately as the temperature was raised, but the general tendency seemed to be towards increased resistance. This may possibly be due to the formation of a non-conducting film by air or gases expelled from the carbon by heat.

9. *Permanent Effect of Current upon Resistance.*

Under certain circumstances the current produces a permanent and not merely temporary effect upon the resistance; that is to say, the resistance of the contacts (so long as they are undisturbed by vibration or otherwise,) is found to be lower or higher after the current has ceased, than it was at first.

Thus, for example, with a pressure of .5 grm. at the point of contact, the resistance measured with a current of one or two milliampères was found to be 10.5 ohms. A current of .15 ampère was then passed through the carbons for 10 seconds; and on again testing with the weak current, the resistance was found to have fallen to 5.8 ohms. With a pressure of 2.5 grms., the same current reduced the resistance from 6.6 to 4.3 ohms. With 5 grms., the resistance was permanently reduced from 4.7 to 3.4 ohms; and with 25 grms. from 2.4 to 2.0 ohms. All these effects were produced by a current of .15 ampère. Stronger currents (up to a certain point) effect greater reductions.

Table VIII.

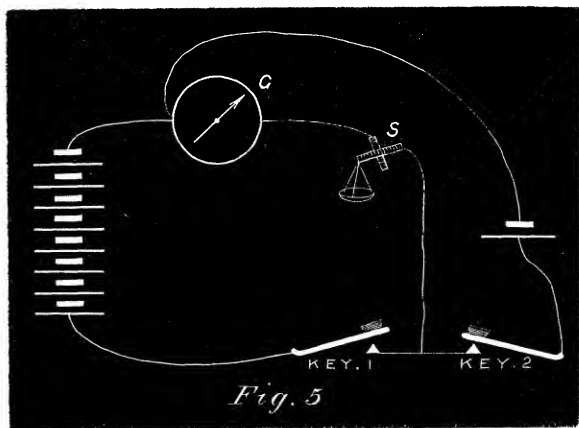
Pressure.		Smallest current with which rise occurred.
Grms.		Ampère.
.05	.....	.02
.1	.....	.05
.15	.....	.10
.2	.....	.19
.3	.....	.17
.4	.....	.29
.5	.....	.37
1	.....	.40
1.5	.....	.43
2	.....	.47
3	.....	.57
4	.....	.51
5	.....	.63

But when the proportion of the current strength to the pressure exceeds a certain limit, the effect of the current is apparently to produce a permanent *increase* in the resistance, and this increase is generally very considerable. The carbon contacts, a tangent galvanometer, a box of resistance coils, and a battery of ten Leclanché cells are connected in simple circuit, and the strength of the current gradually increased by plugging out resistance in the box. As the

current increases, the deflection of the galvanometer needle becomes greater until a certain strength is attained, when the galvanometer needle suddenly goes back, and comes to rest almost or exactly at zero. The lighter the pressure the smaller the current necessary to produce this effect. Table VIII gives the currents with which the rise occurred, the pressure at the points of contact varying from .05 gm. to 5 grms.

Attempts were made to measure the high resistance with a Wheatstone's bridge and a small current, and this brought to light the curious fact that the resistance in question is generally very much lower for weak than for strong currents. Thus it may happen that while the moment before measurement the resistance may be sensibly infinite, the very act of measurement reduces it to a few hundred ohms.

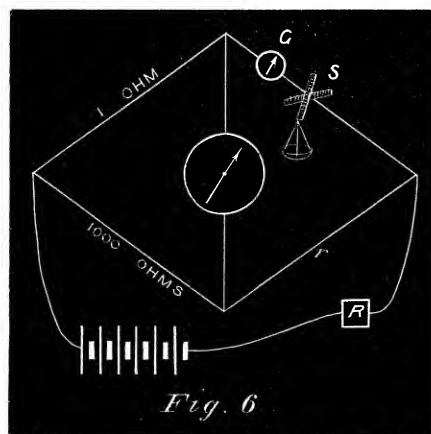
This paradoxical effect is best shown by the special arrangement indicated in fig. 5.



G is the tangent galvanometer, S the carbon balance in the scale-pan of which is a weight of 1 gm. When key 1 is depressed the current from eight Leclanché cells passes through the galvanometer and the carbons. The immediate effect is a deflection of (in the case of my galvanometer) about 75° . Almost instantly, however, the needle returns to zero, and key 1 may now be raised and depressed without producing the slightest movement of the needle. If, however, key 2 is depressed the current from a single cell will pass through the galvanometer and the carbons, and this will generally produce a small deflection of from 2° to 10° . But if key 1 is once more depressed the needle again altogether fails to move. The resistance at S is therefore of a very peculiar nature, being more

easily overcome by a small electromotive force than by a high one. Though the experiment as thus described is generally successful, it occasionally happens that the single cell fails equally with the larger battery to overcome the resistance.

For a systematic investigation of the last-mentioned group of phenomena the apparatus was arranged as shown in fig. 6.



It is essentially a Wheatstone's bridge arrangement, the proportional coils used being 1 and 1,000 ohms. A tangent galvanometer of .9 ohm resistance is inserted in the same arm as the carbon balance, and a box of resistance coils R is placed between the battery (which consists of eight or ten Leclanché cells) and the bridge. The arrangement admits of the measurement of the resistance of the carbon when traversed by strong currents, the strength of which can be regulated by the resistance box R , and measured by the tangent galvanometer G . A given weight being in the scale-pan, known currents of gradually increasing strength were passed through the carbon. The resistance was measured, 1st, while the known current was passing; 2nd, with a very small current obtained by unplugging 10,000 ohms in the resistance box. As the currents increased in strength, the resistance measured with the very small current gradually diminished until a point was reached—and the lighter the weight the sooner this was the case—at which the resistance suddenly became infinity. The measurements are given in Table IX, the currents varying from .01 to .7 ampère, and the pressures from .05 grm. to 5 grms.

Table IX.

R_1 = Resistance with current in first column of table.

R_2 = Resistance with very weak current.

Current. Ampère.	Pressure.							
	·05 gramm.		·5 gramm.		2·5 grms.		5 grms.	
	R_1 .	R_2 .	R_1 .	R_2 .	R_1 .	R_2 .	R_1 .	R_2 .
·01	38	62	10·2	10·3	4·8	4·8	2·60	2·6
·05	21	38	9·7	10·1	4·6	4·7	2·54	2·6
·1	Inf.	..	8·1	9·3	4·4	4·7	2·37	2·5
·2	..	..	6·3	8·4	4·0	4·5	2·23	2·4
·3	..	..	Inf.	..	3·7	4·3	2·11	2·3
·4	..	..	..	..	3·6	4·2	2·01	2·3
·5	..	..	..	..	Inf.	..	1·95	2·2
·6	..	..	..	..	..	..	1·90	2·2
·7	..	..	..	..	..	..	Inf.	..

10. *Experiments with Metallic Contacts.*

For the sake of comparison a few experiments were made with metals. Metallic loose contacts were found to be even more uncertain in their action than those of carbon, and to obtain a really fair average of results a very great number of measurements would be required. Under precisely the same conditions as nearly as they could be reproduced, the results obtained were frequently very different. Nevertheless it has been possible to bring out with sufficient distinctness some remarkable peculiarities in the behaviour of metallic contacts.

The metal principally used was bismuth, which was selected on account of its high specific resistance; but a few experiments were also made with copper and platinum. The cylinders of bismuth and copper were nearly the same diameter as those of the carbon previously used—6 millims. The platinum was prepared by soldering wires of that metal upon cylinders of brass. The balance already described and shown at fig. 1 was used in the same manner as before.

11. *Permanent Fall of Resistance caused by Current.*

The first unexpected phenomenon which attracted notice in working with bismuth was the very great permanent fall in the resistance which was produced by an ordinary current with light pressures. Using a single Leclanché cell, the lightest contact—the pressure being certainly less than ·01 gramm.—failed to give a higher resistance than

9 ohms; but with 400 ohms inserted between the battery and bridge, a pressure of .35 grm. gave a resistance which on different occasions varied between 73 and 110 ohms. When once, however, the resistance has been reduced by a strong current, the changes which occur when feebler currents are used are comparatively small—unless, of course, the points of contact are first separated. Of the nature of such changes I shall say more presently. The following table gives a few measurements, using one Leclanché cell: (1) with a resistance of 300 ohms between the cell and the bridge; (2) without the 300 ohms. It will be understood that the bismuth cylinders were separated from each other every time the weights were changed. The effect in question is most marked with small pressures; with comparatively high pressures it quite disappears.

Table X.

Pressure.	Resistance of bismuth contacts			
	with 300 ohms between battery and bridge.		when the 300 ohms is removed.	
Grms.	Ohms.		Ohms.	
.5		60	.....	1.9
2.5		37.2	.....	1.4
5		5.4	.....	1.7
7.5		7.7	.....	2
10		.8	.....	.8
15		.6	.....	.5
25		.14	.....	.14

12. *Adhesion of Contacts due to Current.*

This phenomenon is accompanied by another. After the passage of the current which has caused the resistance to be so remarkably diminished, the bismuth cylinders are found to adhere to each other, a quite appreciable force being necessary to separate them. This effect, which is common to all metals, has been thoroughly investigated by Mr. Stroh, a description of whose experiments is given in the "Journal of the Society of Telegraph Engineers," vol. xix, page 182. I shall, therefore, say nothing more about it, except that I have succeeded in causing two pieces of very thin platinum wire to stick to each other with a current of about a milliampère. Mr. Stroh attributes the effect to fusion.

13. *Effect of Variation of Current after a strong Current has passed through the Contact.*

A third apparent anomaly is the following: a small weight being in

the scale-pan, let a weak current be caused to pass through the points of contact; the resistance will be found to be high. Let a strong current be passed, and the resistance will be greatly diminished. Once more let the current be reduced to its original strength; the resistance will not rise to its original value; it will not, in fact, rise at all; it will be still further diminished. The following table gives examples of this experiment with pressures of $\cdot 5$, 1, and 5 grms.

Table XI.

Current. Ampère.	Resistance of bismuth contacts with pressure of		
	$\cdot 5$ gm.	1 gm.	5 grms.
$\cdot 01$	8	2.12	1.50
$\cdot 5$	1.27	1.27	1.22
$\cdot 01$	1.22	1.21	1.22
$\cdot 5$	1.27	1.26	1.22
$\cdot 01$	1.22	1.21	1.22

In the last case there is no change after the first fall of resistance. Table XII further illustrates the effect with greater variations of current and of weight, but in the experiments to which it relates the strongest current was used first. As before, the bismuth cylinders were separated only when the weights were changed.

Table XII.—Experiments with Clean Bismuth.

Current. Ampère.	Resistance of contacts with pressure of				
	$\cdot 25$ gm.	$\cdot 35$ gm.	$\cdot 5$ gm.	1 gm.	2 grms.
$\cdot 5$	1.52	1.39	1.55	1.33	1.35
$\cdot 3$	1.40	1.35	1.49	1.30	1.33
$\cdot 1$	1.37	1.33	1.45	1.28	1.32
$\cdot 05$	1.35	1.33	1.44	1.28	1.32
$\cdot 01$	1.18	1.32	1.41	1.28	1.32
$\cdot 05$	1.55	1.33	1.46	1.29	1.32
$\cdot 1$	1.72	1.34	1.47	1.29	1.33
$\cdot 3$	1.79	1.39	1.55	1.31	1.34
$\cdot 5$	1.49	1.43	1.61	1.33	1.35

In order that this experiment may be successful, it is necessary that the surfaces in contact should be absolutely clean. Unless they are scraped immediately before the measurements are made, the opposite

effect may result: that is (after the first great fall of resistance), diminished current may produce increased resistance. Table XIII gives the measurements, with the same currents as before, when the bismuth was first rubbed with the finger, instead of being scraped as had been done in the previous experiments.

Table XIII.—Experiments after Rubbing the Bismuth with the Finger.

Current. Ampère.	Resistance of contact with pressure of		
	·35 grm.	·5 grm.	1 grm.
·5	1·30	1·30	1·22
·3	1·75	1·46	1·28
·1	1·92	1·69	1·29
·05	1·83	1·92	1·29
·01	1·95	2·29	1·29
·05	1·89	2·07	1·28
·1	1·87	1·98	1·28
·3	1·77	1·72	1·27
·5	1·46	1·45	1·27

I think these effects admit of a simple explanation. When the surfaces of the bismuth are clean, contact takes place entirely through the metal. The current heats the metal at the points of contact to an extent which depends upon the current strength; and the resistance, in accordance with the general law, increases with the temperature: strong currents will, therefore, give higher resistance than weak ones. When, on the other hand, the surface is not clean, a film of oxide or some foreign substance is interposed, the resistance of which, like that of carbon, is higher with a weak current than with a strong one.

It is probable that similar effects occur with metals of lower specific resistance than that of bismuth; but their observation is very difficult, and requires more delicate apparatus than that at my disposal. Thus, of forty measurements made with platinum contacts, nineteen results were favourable to the theory, ten adverse to it, and eleven neutral. With copper the indications were even more uncertain.

14. *Effects on Resistance of Varying Pressure with Constant Current.*

The resistance of bismuth contacts at various pressures was measured with fixed currents of ·1, ·01, and ·001 ampère, the method used being the same as in the case of carbon. The mean of several series of such measurements is given in Table XIV, which reveals the existence of a more or less definite law, though the results of the experiments did not agree very closely among themselves.

Table XIV.—Effect of Pressure upon Resistance of Bismuth Contacts with Constant Currents.

Pressure. Grms.	Resistance of contacts with current of		
	·1 ampère.	·01 ampère.	·001 ampère.
·05	5	20·82	182
·1	2	16·92	143·3
·15	2·5	14·60	97·8
·2	3·9	12·60	46
·25	2·6	10·05	41·6
·3	2·4	6·35	16·9
·35	2·1	4·12	21·6
·4	1·9	2·37	30·6
·45	1·5	1·60	18·3
·5	1·45	1·47	3·8
1	·95	1·35	
1·5	·85	·70	
2	·90	·62	
2·5	·70	·30	
3	·50	·15	
3·5	·55	·07	
4	·35	·05	
4·5	·25		
5	·15		

15. *Permanent Reduction of Resistance due to Pressure.*

Repeating with bismuth the experiments already described in the case of carbon, it was clear that the diminution of resistance effected by pressure is generally of a permanent nature, continuing to a great extent after the pressure has been removed (so long as the points of contact remain undisturbed), and thus reversing the case of carbon. With strong currents the variations of resistance were so uncertain and irregular that accurate measurements were impossible; but with a resistance of 300 ohms between the battery and the bridge the effect is very clearly marked. The results of the experiments thus made are tabulated below.

Table XV.

Pressure. Grms.	Resistance of bismuth contacts.					
	Ohms.	Ohms.	Ohms.	Ohms.	Ohms.	Ohms.
·5	10·9	37·5	16·3	14·5	25·5	62
3	1·3	1·7	·5	1	1·1	1·8
·5	1·5	1·7	·5	4·5	5·5	15

The points of contact were, of course, changed for each series of observations, and it should be noted that in the case of the last three (which were not made on the same day as the others) I was less successful in arranging the lever so as to secure perfect freedom from oscillation when the weight was changed.

16. *Summary.*

The following appear to be the most important results of the investigation.

(1.) *Carbon Contacts.*

Changes of pressure produce proportionately greater changes of resistance when the initial pressure is small than when it is great.

Changes of pressure produce proportionately greater changes of resistance with weak currents than with strong currents.

Changes of current produce proportionately greater changes of resistance with small currents than with large currents; and with light pressures than with heavy pressures.

When the resistance of a carbon contact has been reduced by an increase of pressure, it will, on the removal of the added pressure, rise to approximately its original value.

The passage of a current whose strength does not exceed a certain limit, depending upon the pressure, causes a permanent diminution in the resistance, and the stronger the current the greater will be such diminution.

When the strength of the current exceeds a certain limit the resistance is greatly and permanently increased. The greater the pressure the higher will be such limit.

Unless special means are adopted for preserving a constant current, the fall in the resistance which attends increased pressure is greater than that which is due to increased pressure alone; being partly due also to increased strength of current.

It is not proved that the diminished resistance which follows an increase of current is an effect of temperature.

(2.) *Metallic Contacts.*

In the case of bismuth and probably of other metals—

With a given pressure the weaker the current the higher will be the resistance. This effect is most marked when the pressure is small.

Increase in the strength of the current is accompanied by a fall in the resistance, and if the current be again reduced to its original strength, the resulting change in the resistance will be small, and it will in no case return to its original value.

Diminution in the strength of the current is followed by a small

fall in the resistance if the metal is clean, and by a small rise in the resistance if the metal is not clean.

Increased pressure produces a greater fall in the resistance with small pressures than with great pressures, and with weak currents than with strong currents.

The resistance after having been reduced by increased pressure does not return to its original value when the added pressure is removed.

17. *Reasons for the Superiority of Carbon over Metal in the Microphone.*

The above observations may, perhaps, throw some light on a matter which has never hitherto been fully explained. Why does carbon give far better results than any metal when used in the microphone? It seems to me that this question may be answered without much difficulty. The mere fact that a current causes delicately adjusted metal contacts to adhere to each other is sufficient to account for the superior efficiency of carbon. A metal microphone might, indeed, be used to transmit the pitch of a sound, provided that its vibrations were sufficiently powerful to cause actual separation of the points of contact. The fundamental tone might, in this way, be conveyed, but it is clear that the minute superimposed vibrations, due to the upper partials, upon which depends the distinctive character of a particular sound, would be very imperfectly represented if not entirely lost.

In addition to this phenomenon of adhesion, and probably connected with it, are the facts that metallic contacts, unlike those of carbon, do not even approximately recover their original resistance when once it has been reduced by increased pressure or increased current, unless, indeed, complete separation occurs: and even the initial effect of pressure upon resistance is (except with very weak currents), in general, much more marked with carbon than with metals.

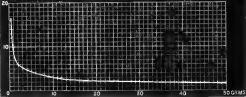
Lastly, it is to be noticed that in the case of carbon, pressure and current act in consonance with each other: pressure diminishes the resistance, and in so doing increases the strength of the current; and the current thus strengthened effects a further diminution in the resistance. In the case of metals, on the other hand (or at least in the case of clean bismuth) pressure and current tend to produce opposite effects. The resistance is diminished by pressure and the current consequently strengthened, but by reason of the increased strength of current, the resistance is *higher* than it would have been if the current had remained unchanged. The effect of this antagonism is not very great, but it seems to give a material advantage to carbon.*

* In April, 1882, I communicated this observation to Mr. Preece, who referred to it in a paper, read at the Southampton Meeting of the British Association, on "Recent Progress in Telephony."



0-10043

Fig. 2



CHMS

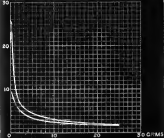


Fig. 3

Figure 1

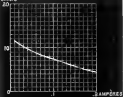


Fig. 1

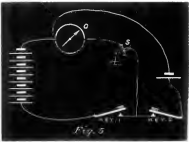




Fig. 11